Orion Ammonia Boiler System Preflight Test Preparations

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ABSTRACT

The Environmental and Life Support Systems branch at Kennedy Space Center (KSC) is currently undergoing preparations for ground testing of the Orion Multi-Purpose Crew Vehicle (MPCV) to prepare its subsystems for EM-1 (Exploration Mission-1). EM-1, Orion's second unmanned flight, is a three-week long lunar mission during which the vehicle will complete a 6-day retrograde lunar orbit before returning to Earth. This paper focuses on the work done during the author's 16-week internship with the Mechanical Engineering Branch of KSC's Engineering Directorate. The author's project involved assisting with the preparations for testing the Orion MPCV's ammonia boiler system, including developing a Concept of Operations (ConOps) for the test, participating in software peer reviews, and developing preliminary fault detection, isolation, and recovery (FDIR) to be used during the test. The purpose of the ammonia boiler system is to keep the spacecraft sufficiently cool during the reentry portion of its mission, from service module separation to post-landing. This system is critical for keeping both the spacecraft (avionics and electronics) and crew alive during reentry, thus a successful test of the system is essential to the success of EM-1.

Nomenclature

ATCS	=	Active Thermal Control System
CAIDA	=	Customer Avionics Interface, Development and Analysis
CMASS	=	Crew Module Ammonia Servicing Subsystem
ConOps	=	Concept of Operations
ECLSS	=	Environmental Controls and Life Support Systems
EFT-1	=	Exploration Flight Test 1
ELSA	=	Emergency Life Support Apparatus
EM-1	=	Exploration Mission 1
EPA	=	Environmental Protection Agency
FDIR	=	Fault Detection, Isolation, and Recovery
GFAST	=	Ground and Flight Application Software Team
GSE	=	Ground Support Equipment
HYPER	=	Hypergolic Fuels
ISS	=	International Space Station
KSC	=	Kennedy Space Center
LCC	=	Launch Control Center
MPCV	=	Multi-Purpose Crew Vehicle
MPPF	=	Multi-Payload Processing Facility
OSHA	=	Occupational Safety and Health Administration
PDU	=	Power and Data Unit
RPSF	=	Rotation, Processing and Surge Facility
SDS	=	Safety Data Sheet
SLS	=	Space Launch System
SRB	=	Solid Rocket Booster
SSPF	=	Space Station Processing Facility
VAB	=	Vehicle Assembly Building

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I. Introduction

The ammonia boiler system is part the Orion spacecraft's Active Thermal Control System (ATCS), one of seven subsystems that make up the spacecraft's Environmental Controls and Life Support Systems (ECLSS). The purpose of the ATCS is to reject excess heat loads produced by the crew and avionics. Excessive heat loads can lead to damage of the spacecraft's electronics and produce an uncomfortable working and living environment for the crew. The ATCS is comprised of heat transport loops, radiators, and supplemental cooling devices that work in conjunction to keep the spacecraft sufficiently cooled. The ammonia boiler system is a supplemental cooling device that works by evaporating ammonia in a heat exchanger that provides coolant fluid to the spacecraft. The system utilizes the low boiling point of ammonia to reject heat from the coolant loops as they pass through the heat exchangers, maintaining temperature control.

Figure 1. Orion Multi-Purpose Crew Vehicle (MPCV) Credits: NASA

Post service module separation, the ammonia boiler system is the only cooling system that remains active on the spacecraft. Should an anomaly occur in the system, the health of the crew and spacecraft electronics would be at high risk. Thus, a successful test of the ammonia boiler system is a crucial step in the process of preparing the spacecraft for flight. For the EM-1 test of the ammonia system, the spacecraft will be serviced with ammonia, the coolant system will be activated, and multiple ATCS configurations will be tested. The purpose of this project was to produce a detailed outline of the procedure for the ammonia boiler system functional test, including vehicle commands, flight hardware, and ground support equipment (GSE). The author spent a significant portion of the project timeline learning the design and function of the system, as well as gathering and verifying the information necessary to develop a detailed procedure. The Environmental and Life Support Systems branch plans to test the ammonia boiler system in early 2018.

II. Objectives

The objectives for this project were broken down into the following two categories: Learning Objectives and Project Objectives. Completion of the Learning Objectives was necessary in order to complete the Project Objectives. The Learning Objectives provided knowledge and understanding, while the Project Objectives produced deliverables.

A. Learning Objectives

I. Learn and understand the hazards and mitigation of ammonia and gaseous nitrogen
II. Understand the cleanliness requirements for ground support equipment of fluid systems

III. Read safety data sheets (SDS) for ammonia and nitrogen and understand EPA/OSHA regulations and handling procedures
IV. Develop an understanding of the control documents, fluid/mechanical schematics, and electrical block diagrams for the vehicle and how system components work together
V. Understand the Crew Module Ammonia Servicing Subsystem (CMASS) and its use as related to the ammonia boiler test
VI. Develop ground software knowledge by supporting the ECLSS/HYPER Ground and Flight Application Software Team (GFAST)

B. Project Objectives

I. Develop a detailed outline of the EM-1 ammonia boiler test, including command and control of the vehicle and ground support equipment
II. Develop a list of issues and questions regarding the ammonia boiler test and/or the project as a whole to be resolved during teleconferences with Lockheed Martin
III. Support test operations for CMASS and GFAST

III. Technical Approach

Learning and Project Objectives were completed by utilizing resources and trainings provided by KSC. The following resources include technical reports, drawings, and conferences. The trainings cover safety, software, and building access.

A. Orion ECLSS schematics

In order to develop an understanding of how the vehicle's fluid/mechanical and electrical components work together, an understanding of the Orion ECLSS schematics for EM-1 was necessary. These schematics provided knowledge of where individual components obtain their power and how to command and control them through a software interface. The schematics enabled the author to create a matrix containing each individual component (valves, temperature sensors, pumps, pressure transducers) and its respective power source and commands. This matrix was helpful with quick identification and verification of vehicle commands in the test procedure outline.

B. MPCV 70156: Cross Program Fluid Procurement and Use Control Specification

This document establishes the requirements and limitations for introducing fluids into flight hardware for ground testing operations at KSC. This document was referenced to understand the cleanliness requirements for ground support equipment of fluid systems.

C. Lockheed Martin teleconferences

Teleconferences with Lockheed Martin assisted with gaining knowledge about the vehicle's systems that was not widely available to the Environmental and Life Support Systems branch, including updated vehicle commands and ammonia system configurations to be tested.

D. EFT-1 (Exploration Flight Test-1) boiler test requirements and procedures

These documents served as a template for the EM-1 boiler test requirements and procedures and assisted with completing the Project Objectives.

E. CMASS drawings

The CMASS drawings assisted with understanding the CMASS and its use as related to the ammonia boiler test.

F. ECLSS Software Support Manual for the Orion Flight Test 1 Vehicle

This document explains the connections between the vehicle's software and hardware for EFT-1 and was used as a baseline for developing the procedure for the EM-1 ammonia system functional test.

G. GFAST software trainings or familiarization

Familiarization with certain software programs, such as C++, as well as attendance at the ECLSS/HYPER GFAST bi-weekly and weekly meetings, assisted with completion of Learning Objective IV.

H. Laboratory Safety Training

This training is required of all personnel at Kennedy Space Center (KSC). The training covers the hazards that exist at KSC and how injuries from these hazards can be prevented.

I. MPPF Access

Several trainings had to be completed in order to gain access to the Multi-Payload Processing Facility (MPPF). One of these trainings is Emergency Life Support Apparatus (ELSA) training, which is required by OSHA for personnel working in the MPPF. The ammonia boiler test and other routine procedures will be conducted in the MPPF, thus the author required access to this facility.

IV. Project Schedule

This project spanned the duration of the author's 16-week internship. The first eight weeks focused on completing the Learning Objectives and gaining an understanding of the vehicle and the ammonia boiler system. The second eight weeks of the project were operations-based and consisted of producing deliverables and supporting GFAST testing. A detailed project schedule is located in the Appendix.

V. Weeks 1-8: System Familiarization

The first eight weeks of the author's project focused on vehicle and nomenclature familiarization. The author studied schematics of the Orion Multi-Purpose Crew Vehicle (MPCV) and was able to create a component matrix that includes the vehicle's effectors, sensors, and valves and links them to their respective item number, description, and interface. The interface refers to where the components receive their power (i.e. which power and data unit (PDU) a component connects to). The matrix also allowed for easy identification of which pumps, valves, and sensors are designated as primary or secondary. This was helpful later on when working with vehicle commands. During the first half of the project, the author began developing a Concept of Operations (ConOps) for the ammonia system functional test that will be used by the ECLSS/HYPER Ground and Flight Application Software Team (GFAST). The ECLSS/HYPER GFAST is writing the ground software displays that will be used to service Orion in the MPPF and on the launch pad. The ConOps for the ammonia system functional test is a high-level summary of how the system will be used from an operational perspective. The ConOps includes vehicle power-up and power-down, but focuses on the series of five individual system tests that will be performed during the test at large. Completion of this ConOps allows the ECLSS/HYPER GFAST to begin writing the software and creating displays for use during upcoming testing.

The author completed several walkdowns of the MPPF in the first eight weeks of the project. The MPPF is the "gas station" for the Orion crew and service modules. This facility contains a high bay and a low bay where the crew module and service module tanks are serviced with oxygen, nitrogen, ammonia, and other fuels that are necessary for a trip to the moon and back. Accordingly, the Crew Module Ammonia Servicing Subsystem (CMASS) is housed in the MPPF. As the name implies, the CMASS is used to service and de-service the vehicle's ammonia system before and after flight. While the author did not work with the CMASS directly, it was necessary for her to gain an understanding of how the system works in order to understand its place in the ammonia boiler test ConOps.

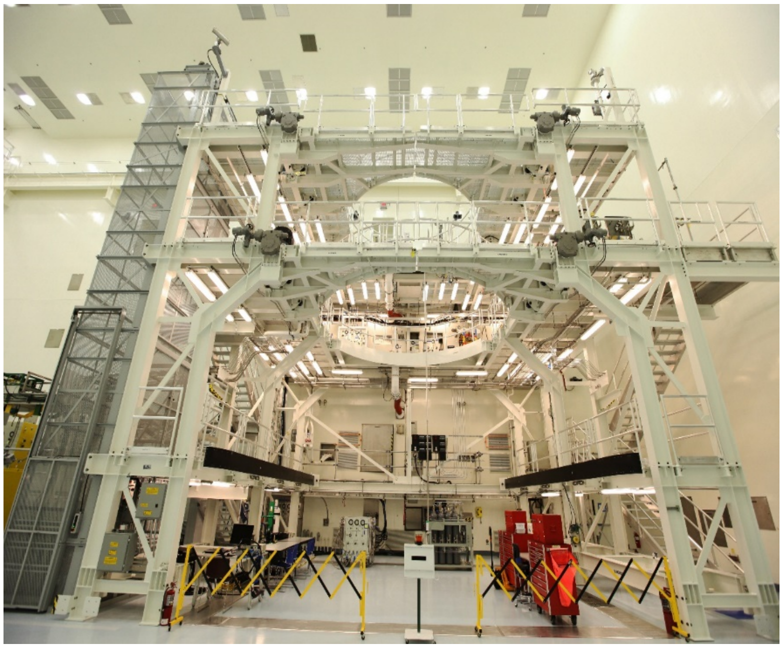

Figure 2. Orion Service Platform, MPPF   Credits: NASA

During week seven, the author participated in the first of three scheduled teleconferences with Lockheed Martin in order to present this ConOps and receive feedback regarding planned test operations. The Environmental and Life Support Systems branch learned valuable information including different command sequences that have been modified or eliminated since EFT-1. The branch also learned how the test configurations for the EM-1 ammonia functional test differ from those used in the EFT-1 test, which was important information to include in the ConOps. The meeting was successful and answered most of the questions that the author put together over the last eight weeks with the help of her mentors. This first teleconference also brought to light some communication gaps between NASA and Lockheed Martin regarding predetermined test requirements. This teleconference reinforced the importance of open and frequent communication between NASA and its contractors and was a valuable learning opportunity for the author.

VI. Weeks 9-16: Pre-flight Test Preparations

Weeks 9-16 focused on developing a detailed outline for the ammonia functional test procedure, assisting with validation operations in the MPPF, and continuing to support the ECLSS/HYPER GFAST. The goal for the end of the project was to develop a highly detailed outline of the procedure for the ammonia system functional test, including vehicle commands and configurations and GSE. The tasks during the last eight weeks of the project focused on obtaining the information necessary to populate the detailed outline, continuing support of ECLSS/HYPER GFAST operations, and assisting with CMASS operations.

Figure 3. CAIDA Lab Located Inside the LCC   Credits: NASA

The author assisted the ECLSS/HYPER GFAST with testing in Customer Avionics Interface, Development and Analysis (CAIDA) lab in Launch Control Center (LCC). The CAIDA lab is a simulation environment that employs DEWEsoft, a data acquisition and testing software that is used to run simulations with a model of Lockheed Martin's Orion FSW. During testing, the ECLSS/HYPER GFAST ran into several issues with the FSW model. For example, if they set a coolant loop pump control command to "Pump A On," they knew that a value of 1 should be assigned to that parameter. However, in some cases the resulting value would not change at all. Since CAIDA uses different scripts (files that execute a series of commands) than Lockheed Martin uses in their own FSW testing lab, the author's job was to filter through both the CAIDA and Lockheed Martin scripts to look for dissimilarities that might be causing the Orion FSW model in the CAIDA lab to respond erroneously.

The greatest challenge the author faced with this project was trying to gather updated data on valid vehicle commands. Since Lockheed Martin is writing the flight software (FSW) for the Orion Crew Module, updated commands are not readily available at KSC. The author attempted to solve this problem by gathering the commands used in the EFT-1 Ammonia Boiler Test and trying to determine what the new, EM-1 commands are based on a few command spreadsheets that were available. These "guesses" are to be validated or modified in future teleconferences with Lockheed Martin, or upon receiving new information.

The author continued to support CMASS and GFAST operations during the second half of the project. She attended the ECLSS/HYPER GFAST Peer Review that covered the ammonia system functional test ConOps, the vehicle power-up ConOps, and the vehicle power-down ConOps. The group discussed and resolved comments on these documents at the meeting. In addition, the author had the opportunity to support helium sampling operations in support of CMASS in the MPPF. The CMASS uses gaseous helium to pressurize the ammonia tanks in the crew module and the system must pass cleanliness tests before it can be used to service flight hardware.

The author spent the final weeks of the project developing Fault Detection, Isolation, and Recovery (FDIR) for use during the ammonia system functional test. According to Wander and Förstner, "A fault is defined as an undesired deviation of at least one characteristic property of a system variable from an acceptable/nominal behavior that leads to degraded overall system performance, malfunctions or failure of the system."[1] When a vehicle fault is detected, it is then isolated (the location of the fault is determined), and the proper response is taken to compensate for the fault, such as commanding a valve open or closed, or switching to a redundant system. Since no FDIR is currently available for the ammonia system functional test, test conductors will have to manually safe the vehicle in the event of an ammonia leak or other anomaly that could risk the safety of personnel inside the MPPF and compromise the vehicle. Developing FDIR for this test will greatly reduce any risks associated with the test and will increase response time should a fault or leak be detected during testing.

VII. Conclusion

The author was able to draft a detailed outline of the procedure for the ammonia system functional test. More work will need to be done on the vehicle power-up and power-down portions of the procedure, but the ammonia system testing portion of the procedure is thorough and includes vehicle test configurations, vehicle commands, and GSE. The author was able to compile a substantial list of questions regarding the ammonia system functional test with the help of her mentors. A significant number of these questions were answered in the teleconferences with Lockheed Martin.

VIII. Additional Learning Opportunities

The author had the opportunity to participate in two exciting learning opportunities in addition to working on this project. The first was a tour of the high bay located inside the Space Station Processing Facility (SSPF). While touring this facility, Orbital ATK's OA-7 Cygnus cargo delivery spacecraft was being prepped for its upcoming resupply mission to the International Space Station (ISS). The author will have the opportunity to watch the launch of this spacecraft on top of an Atlas V rocket from Cape Canaveral in April.

Figure 4. OA-7 Cygnus Capsule, SSPF Credits: NASA

The author also had the opportunity to tour the Rotation, Processing and Surge Facility (RPSF). The RPSF is the facility where the solid rocket booster (SRB) segments are received by rail car, transitioned to the vertical position by crane, and stacked before making the trip across the street to the Vehicle Assembly Building (VAB). Upon arrival to the VAB, the SRBs will be joined to the Space Launch System (SLS) and bolted to the crawler transporter platform. The SRBs that will be used as part of the SLS contain 1.5 million pounds of propellant each. The author is an active member of several undergraduate research projects involving composite solid rocket propellant, so this was an incredible experience for her.

Figure 5. Aft Skirt SRB Segment, RPSF Credits: Julia Levitt

Appendix

Tasks	Start Date	End Date	Week
• Complete project plan by 1/27/17 • Complete GFAST training • Orion vehicle schematic familiarization • Support Lockheed Martin teleconferences • Develop component matrix including power and data interfaces • CMASS familiarization • Support MPPF validation operations and teleconferences	1/23/17	2/3/17	1-2
• Update test schematic and PowerPoint • Develop vehicle and Boiler test requirements • Continue software training • Support MPPF validation operations and teleconferences • Attend and support GFAST meetings	2/6/17	2/17/16	3-4
• Obtain vehicle ECLSS control/command documents • Summarize controls including FDIR, control limits, flow, temperature • Support MPPF validation operations and teleconferences • Attend and support GFAST meetings	2/20/17	3/3/17	5-7
• Produce draft of test outline with Ground Support Equipment (GSE) • Other training as necessary • Support MPPF validation operations and teleconferences • Attend and support GFAST meetings	3/6/17	3/17/17	8-9
• Develop detailed test procedure with command/control and GFAST commands	3/20/17	4/14/17	10-13
• Develop final report	4/17/17	4/21/17	14

Table 1. Project Schedule

Acknowledgments

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